4.5 Design of alluvial canal

Kennedy's Theory

Kennedy carried out research on Upper Bari Doab Canal system in Punjab (Pakistan)
Canals which had not required significant silt clearance and maintenance were selected for study and were considered to be stable.

Following are the conslucions drawn from the Kennedy's theory:

i) Silt carried by water flowing in a canal is kept in suspension by the vertical component of eddies generated over the full width of the canal.
ii) Eddies generated from the side slopes are mostly horizontal and do not support the silt.
iii) Critical velocity Vo is mean velocity which will just keep the canal free from silting and scouring.
iv) Bed width of the canal has no effect on critical velocity.

- By practical observations, he gave an empirical relation for critical velocity

$$v_o = 0.55D^{0.64}$$

Where, v_o= critical velocity

D= flow depth in meter

- Kennedy also observed that the critical velocity also depends upon the size of silt, grade of silt, silt carrying capacity and modified the formula introducing a factor called critical velocity ratio m

$$Thus, v_o = 0.55mD^{0.64}$$

m<1 for fine

m>1 for coarse

Kutter's equation for mean velocity of flow in canal

$$v = c\sqrt{RS}$$

$$c = \frac{\frac{1}{n} + (23 + \frac{0.00155}{S})}{1 + (23 + \frac{0.00155}{S})\frac{n}{\sqrt{R}}}$$

R= hydraulic mean depth
S= bed slope of canal
N=rugosity coefficient of canal bed.

Design steps:

Case1: Given Q, N, m, and S

- Assume trial value of D
- Calculate $v_o = 0.55mD^{0.64}$
- Calculate cross sectional area of flow
- Assume suitable side slopes(if not given) and calculate R
- Calculate mean velocity of flow V using Kutter's equation. If the velocity is nearly same as that in step 2 then the assumed depth is correct else assume another value of D and repeat.

Case 2: Given Q, N, m, and B/D ratio

- Calculate A in terms of D i.e B/D= x or B=xD
- Formulate an equation in D using $v_o = 0.55mD^{0.64}$ and solve for D
- Calculate B and R
- Calculate $v_o = 0.55mD^{0.64}$
- Knowing V, R, and N calculate canal bed slope using Kutter's equation.

Numerical

1) Design an irrigation canal to carry a discharge of 5 cumec. Assume N=0.0225 and m=1. The canal has a bed slope of 0.2 m per kilometer.
2) Design an irrigation canal to carry a discharge of 5 cumec. Assume N=0.0225, m=1 and B/D=3.24 using Kennedy's theory. Assume side slope of 0.5:1

Assume side slope ½:1

QN1

1) Assume trial depth $D = 0.8\,m$

2) $V_o = 0.55 \times m D^{0.64} = 0.55 \times 1 \times (0.8)^{0.64} = 0.476\ m/s$

3) Area $A = \frac{Q}{V_o} = \frac{5}{0.476} = 10.504\,m^2$

$A = BD + zD^2 = B \times 0.8 + \frac{0.8^2}{2}$

or, $10.504 = B \times 0.8 + \frac{0.8^2}{2}$

$\therefore B = 12.73\,m$

Perimeter $P = B + 2D\sqrt{z^2+1}$ $(B + D\sqrt{5})$

$= 12.73 + 2 \times 0.8 \sqrt{(1/2)^2 + 1}$

$= 12.73 + 0.8\sqrt{5}$

$= 14.51\,m$

$\therefore R = \frac{A}{P} = \frac{10.504}{14.51} = 0.724$

4) $V = \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{R}}} \times \sqrt{RS}$

$V = \frac{23 + \frac{1}{0.0225} + \frac{0.00155 \times 1000}{0.2}}{1 + \left(23 + \frac{0.00155 \times 1000}{0.2}\right) \times \frac{0.0225}{\sqrt{R}}} \times \sqrt{R \times \frac{0.2}{1000}}$

$= \frac{1.06}{1 + \frac{0.691}{\sqrt{R}}} \times \sqrt{R} = \frac{1.06}{1 + \frac{0.691}{\sqrt{0.724}}} \times \sqrt{0.724} = 0.498\ m/s$

Since $V_o < V$, increase 'D'

$D = 1.0\,m$

1) $V_o = 0.55 \times 1 \times (1)^{0.64} = 0.55\ m/s$

2) $A = \frac{5}{0.55} = 9.09\,m^2$

$B = 8.59\,m$

$P = 10.83\,m$

$R = \frac{A}{P} = 0.84$

3) $V = \frac{1.06}{1 + \frac{0.691}{\sqrt{R}}} \times \sqrt{R} = \frac{1.06}{1 + \frac{0.691}{\sqrt{0.84}}} \times \sqrt{0.84}$

$= 0.553\ m/s$

$V \approx V_o$, $\therefore$ adopted D is correct.

QN2

Solⁿ:

$\frac{B}{D} = 3.24$, $z:1 = 1/2:1$

Area $(A) = BD + zD^2$

or, $A = BD + \frac{D^2}{2}$

or, $A = D^2\left(\frac{B}{D} + 0.5\right)$

or, $A = D^2 \times (3.24 + 0.5)$

$\therefore A = 3.74D^2$ — ①

$V_o = 0.55 m D^{0.64}$

$V_o = 0.55 \times 1 \times D^{0.64}$

$Q = A \times V_o$

or, $5 = (3.74D^2) \times (0.55 \times D^{0.64})$

or, $D = \left[\frac{5}{3.74 \times 0.55}\right]^{\frac{1}{2.64}}$

$\therefore D = 1.40 m$.

$\therefore B = 3.24 D = 3.24 \times 1.40 = 4.54 m$.

$R = \frac{BD + \frac{D^2}{2}}{B + D\sqrt{5}} = \frac{4.54 \times 1.4 + \frac{1}{2}(1.4)^2}{4.54 + 1.4\sqrt{5}}$

$\therefore R = 0.956$

$V_o = 0.55 \times 1 \times (1.4)^{0.64} = 0.682 m/s$.

From Kutter's eqn;

$$V = \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{R}}} \times \sqrt{RS}$$

or, $$0.682 = \frac{23 + \frac{1}{0.0225} + \frac{0.00155}{S}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{0.0225}{\sqrt{0.956}}} \times \sqrt{0.956 S}.$$

On solving above equation,

$$\boxed{S = \frac{1}{4000}}$$

Drawbacks of Kennedy's theory

- Significance of B/D ration isn't considered in the theory.
- The complex phenomenon of silt transportation and silt characteristics is simply considered by a factor 'm'
- Design procedure involves trial and error method
- This theory is aimed to design an average regime channel.
- Kennedy uses kutter's formula. So, all the defects of Kutter's formula are associated with Kennedy's formula.

Lacey's Regime theory:

As per Lacey, for a canal constructed in alluvium to carry a certain discharge the width, depth, and bed slope of the canal will undergo modification by silting and scouring till equilibrium is attained.

Such a canal is called regime canal. There are 3 regime conditions:

a) True regime

An artificially induced/constructed canal having a certain fixed section and slope can behave in true regime if the following conditions are satisfied.

Discharge is constant

Flow is uniform

Silt discharge is constant

Silt grade i.e. type and size of silt is constant

Thus, true regime is rare and a canal can't practically be in true regime. It means the canal will either be in initial regime or final regime.

b) Initial regime

- A canal is said to be in 'initial regime' if only bed slope varies due to silt dropping but the cross section and wetted perimeter remains unaffected.
- When water flows through excavated canal with somewhat narrower dimension and defective slope, the silt carried by the canal may get deposited in upper reaches and bed slope may increase resulting increase in velocity. The increase in velocity results in non silting condition called initial regime

In practice, the sides are protected or grassed and hence it is not scoured.

c) Final regime

- If there is no resistance from sides, all the canal section variable such as depth, area, perimeter etc. are actually free to vary and finally gets adjusted to a suitable value according to discharge and silt grade. This is called final regime state.
- Regime theory is applicable only to canal in final regime. The stable cross section has tendency to attain semi elliptical shape.

Design of canal by Lacey's theory

Following empirical equations has been proposed by Lacey:

$$v = \sqrt{\frac{2}{5} f R} \quad \text{..... (1)}$$

$$Af^2 = 140v^5 \quad \text{..... (2)}$$

$$v = 10.8R^{2/3}S^{1/3} \quad \text{..... (3)}$$

Where, v= mean velocity of flow in m/s

f= silt factor = $1.76\sqrt{d_{mm}}$

R= hydraulic radius

d_{mm}= average size of particle in mm (d_{50})

A= cross section area in m^2

S= bed slope

Design of canal by Lacey's theory

Relations derived from Lacey's fundamental formulas

1. Hydraulic Radius:

$$R = \frac{5}{2}\left(\frac{v^2}{f}\right)$$

2. Flow velocity, discharge and silt factor relation:

$$v = \left({}^{Qf^2}/_{140}\right)^{1/6}$$

3. Perimeter discharge relation:

$$P = 4.75\sqrt{Q}$$

4. Regime slope equation:

$$S = \frac{f^{5/3}}{3340Q^{1/6}} \qquad S = \frac{f^{3/2}}{4980R^{1/6}}$$

5. Lacey's regime scour depth relation:

$$R = 0.473\left(\frac{Q}{f}\right)^{\frac{1}{3}} \ (R \ is \ scour \ depth \ not \ hydraulic \ radius)$$

6. Lacey's normal scour depth relation:

$$R = 1.35\left(\frac{q^2}{f}\right)^{\frac{1}{3}} \ (R \ is \ scour \ depth \ not \ hydraulic \ radius)$$

Derive P-Q Relation

V-Q-f relation

$$Q = AV$$

$$Q = \frac{140V^5}{f^2} \times V \qquad \left[\because A = \frac{140V^5}{f^2}\right]$$

$$Qf^2 = 140V^6 \quad \text{——} (x)$$

$$\therefore V = \left(\frac{Qf^2}{140}\right)^{1/6}$$

P-Q Relation:

We have,

$$V = \sqrt{\frac{2}{5} fR}$$

Raising power by '4'

$$V^4 = \frac{4}{25} f^2 R^2$$

or, $$\frac{4}{25} f^2 R^2 = V^4 \quad \text{——} (y)$$

Dividing eqn (x) by (y)

$$\frac{Qf^2}{\frac{4}{25} f^2 R^2} = \frac{140V^6}{V^4}$$

or, $$\frac{25Q}{4R^2} = 140V^2$$

Since, $R = \frac{A}{P}$; $Q = AV$ we get

$$\frac{25Q}{4(A/P)^2} = 140V^2$$

$$P^2 Q = \frac{560}{25}(AV^2)^2$$

$$P^2 = 22.4Q$$

$$P = 4.75\sqrt{Q} \quad \text{——} (iii)$$

P = perimeter in m.

Design steps

Design steps for Lacey's theory

- Calculate velocity from the equation

$$v = \left(Qf^2/140\right)^{1/6}$$

- Compute area of channel

$$Q = Av$$

- Compute perimeter

$$P = 4.75\sqrt{Q}$$

- Solve these two equations to get dimension of channel

$$A = (b + zy)y \; and \; P = b + 2y\sqrt{1 + z^2}$$

- Compute bed slope using

$$S = \frac{f^{5/3}}{3340Q^{1/6}}$$

Numerical

1) A canal is to be designed for the following data: Discharge 5 cumec, silt factor 1.0, side slope 0.5:1.
2) The slope of a canal in alluvium is 1 in 4000. Lacey's silt factor is 0.9 and side slope is 0.5:1. Find the canal section and maximum allowable discharge which can be passed through it.

QN1

1) velocity $(V) = \left(\frac{Q}{140}\right)^{1/6}$

$= \left[\frac{5(1.0)^2}{140}\right]^{1/6}$

$= 0.574$ m/s.

2) Area $A = \frac{Q}{V} = \frac{5}{0.574} = 8.71 m^2$.

3) Perimeter $P = 4.75\sqrt{Q} = 4.75\sqrt{5} = 10.62$ m

4) $A = BD + \frac{1}{2} \cdot D^2$

or, $8.71 = BD + 0.5D^2$ —— (i)

$P = B + 2D\sqrt{Z^2+1}$

$= B + 2D\sqrt{\left(\frac{1}{2}\right)^2+1}$

$10.62 = B + D\sqrt{5}$ —— (ii)

Solving eqn (i) and (ii), we get

$B = 8.44$m, $D = 0.98$m

5) $R = \frac{A}{P} = \frac{8.71}{10.62} = 0.82$.

6) Bed slope $= S = \frac{(5)^{5/3}}{3340(Q)^{1/6}} = \frac{1}{3340 \times (5)^{1/6}} = \frac{1}{4400}$

Soln:

$S = \frac{1}{4000}$, $f = 0.9$

We know,

$$S = \frac{f^{5/3}}{3340 Q^{1/6}}$$

or, $\frac{1}{4000} = \frac{(0.9)^{5/3}}{3340 Q^{1/6}}$ $\therefore Q = 1.03 \, m^3/s$

Now,

$$V = \left(\frac{Q f^2}{140}\right)^{1/6} = \left(\frac{1.03 \times 0.9^2}{140}\right)^{1/6} = 0.425 m/s$$

$$A = \frac{Q}{V} = \frac{1.03}{0.425} = 2.42 m^2$$

$$P = 4.75\sqrt{Q} = 4.75\sqrt{1.03} = 4.82 m$$

We know,

$A = BD + ZD^2 = 2.42$

$BD + \frac{D^2}{2} = 2.42$ ——— (i)

$P = B + 2D\sqrt{Z^2+1} = 4.82$

or, $B + 2D\sqrt{(0.5)^2+1} = 4.82$

or, $B + D\sqrt{5} = 4.82$ ——— (ii)

Solving (i) and (ii) we get quadratic eqn

$1.73D^2 - 4.82D + 2.42 = 0$

Solving $D = 0.65 m$ or $2.12 m$

QN2

when $D = 0.65 m$

from eqn (ii) $B = 4.82 - D\sqrt{5} = 3.36 m$

when $D = 2.12 m$

from eqn (ii) $B = 4.82 - D\sqrt{5} = 0.08 m$ (not possible)

$\therefore D = 0.65 m$ and $B = 3.36 m$

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Drawbacks of Lacey's theory

1) The characteristics of a regime canal are not precisely defined.
2) The true regime condition defined by Lacey may not be achieved in actual practice.
3) Silt discharge and silt grade have not been properly defined and simply represented by a factor 'f'.

4.6 Design of canal lining

Defn: Process of treating canal boundary to make canal impervious and increase permissible flow velocity.

Advantages of canal lining:

- It helps in seepage control.
- It helps in preventing water logging.
- Increases discharge capacity of canal.
- Increases duty of irrigation water.
- Reduction in general maintenance and repair cost.

Requirements of good canal lining materials.

- Economy:

should be economic in initial cost as well as during repair and maintenance

- Structural stability:

Should be able to withstand seepage pressure

- Durability

Should be able to withstand natural tear due to velocity of water, rain, sunshine, frost, thermal and moisture changes

- Reparability

Should be such that it can be repaired easily on damage over time period

- Impermeability

Should posses minimum permeability

Economic analysis (Justification for lining the existing canal)

a) Annual benefits

Suppose, m cumec water is saved by lining the canal

And the cost of irrigation water to farmers = R_1 rupees per cumec

Let annual cost of maintaining existing unlined canal = R_2 rupees

Suppose p% of maintenance cost is saved due to lining of canal

Thus, annual benefits (AB) = mR_1+pR_2

b) Annual costs

Suppose, the capital expenditure required for lining = C rupees

Life period of lining = Y years

Annual depreciation charges = C/Y

Let r be the annual rate of interest

Then interest on capital expenditure =0.5*C*r/100

Thus, total annual cost (AC) = C/Y+0.5*C*r/100

Hence, benefit cost ratio = AB/AC

For the economic justification, AB/AC should be greater than 1

Design of various lined canal section

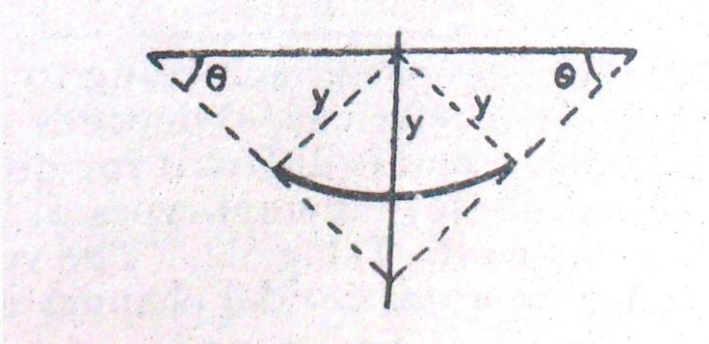
1) Triangular section (for small discharge)

Let central depth = radius of circle = y

$$A = 2 * \pi * y^2 * \frac{\theta}{2\pi} + 2 * \frac{1}{2} * y * ycot\theta$$

i.e. $A = y^2\theta + y^2 cot\theta$

Thus, $A = y^2(\theta + cot\theta)$



$$Perimeter\ (P) = 2 * y * cot\theta + 2 * 2\pi * y * \frac{\theta}{2\pi}$$

i.e. $P = 2y\theta + 2ycot\theta = 2y(\theta + cot\theta)$

Hence , hydraulic radius, R=A/P= y/2

Design of various lined canal section

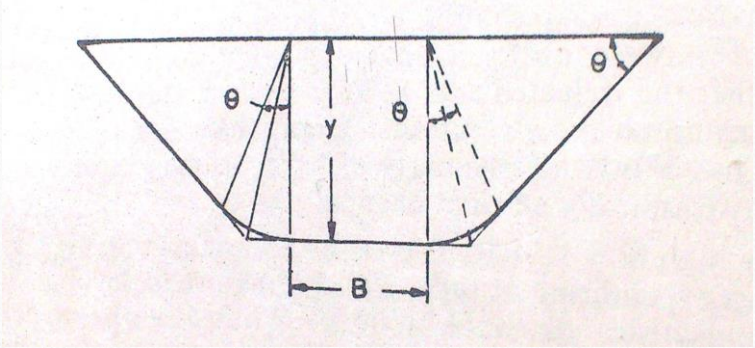
2) Trapezoidal section(for large discharge)

Let depth = radius of circle = y

$$A = By + 2\pi y^2 * \frac{\theta}{2\pi} + 2 * \frac{1}{2} * y * ycot\theta$$

i.e. $A = By + y^2\theta + y^2 cot\theta$

Thus, $A = By + y^2(\theta + cot\theta)$



$$Perimeter\ (P) = B + 2 * y * cot\theta + 2 * 2\pi * y * \frac{\theta}{2\pi}$$

i.e. $P = B + 2y\theta + 2ycot\theta = B + 2y(\theta + cot\theta)$

Design of various lined canal section

2) Trapezoidal section(for large discharge)

Let depth = radius of circle = y

$$A = By + 2\pi y^2 * \frac{\theta}{2\pi} + 2 * \frac{1}{2} * y * ycot\theta$$

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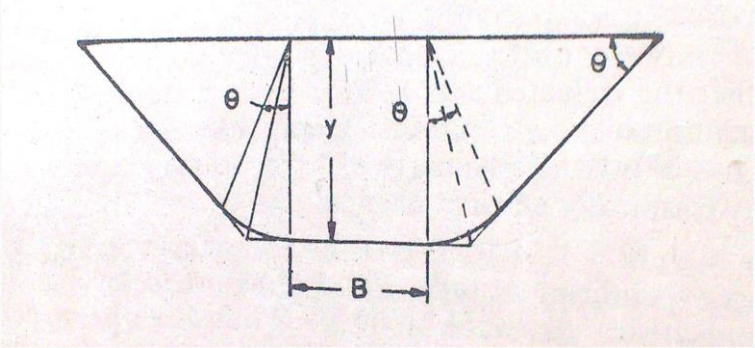
Thus, $A = By + y^2(\theta + cot\theta)$



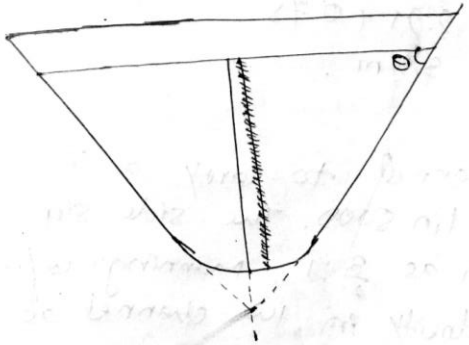
$$Perimeter\ (P) = B + 2 * y * cot\theta + 2 * 2\pi * y * \frac{\theta}{2\pi}$$

i.e. $P = B + 2y\theta + 2ycot\theta = B + 2y(\theta + cot\theta)$

Numerical

1) Design a lined canal to carry a discharge of 15 cumec. The available and accepted country slope is 1 in 9000. Assume good brick lining with Manning's coefficient 0.015. Side slopes is 1.25:1. Design as a triangular section.
2) Design a concrete lined canal to carry a discharge of 350 cumec at a slope of 1 in 5000. The side slopes of the canal may be taken as 1.5:1. Manning's coefficient is 0.014. Assume limiting velocity in the canal as 2m/sec.

QN1



$\tan\theta = \frac{1}{5/4} = \frac{1}{1.25}$

$\therefore \cot\theta = 1.25$

$\therefore \theta = 0.675$ radians.

Area $(A) = y^2(\theta + \cot\theta)$

$= y^2(0.675 + 1.25)$

$\therefore A = 1.925y^2$

Perimeter $(P) = 2y(\theta + \cot\theta)$

$= 2y(0.675 + 1.25)$

$\therefore P = 3.85y.$

$R = \frac{A}{P} = \frac{1.925y^2}{3.85y} = 0.5y.$

Using manning's formula,

$Q = \frac{1}{n} \cdot A \cdot R^{2/3} S^{1/2}.$

$\text{or, } 15 = \frac{1}{0.015} \times 1.925y^2 \times (0.5y)^{2/3} \times \left(\frac{1}{9000}\right)^{1/2}$

Solving for 'y'

$y = 2.95m$

Provide free board of 0.75m

$\therefore$ Total depth of channel $= 2.95 + 0.75$

$= 3.7m.$

QN2

Solution

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$2 = \frac{1}{0.014} \times R^{2/3} \left(\frac{1}{5000}\right)^{1/2}$$

$$\therefore R = 2.79\,m$$

$$\tan\theta = \frac{1}{3/2} = \frac{1}{1.5}$$

$$\therefore \cot\theta = 1.5 \quad , \quad \theta = 0.59 \text{ radians.}$$

Now,

$$A = y(B + y\theta + y\cot\theta)$$

$$= y(B + 0.59y + 1.5y)$$

$$\therefore A = y(B + 2.09y) \quad \text{—— (1)}$$

$$P = B + 2y\theta + 2y\cot\theta$$

$$= B + 2 \times 0.59y + 2 \times 1.5y$$

$$\therefore P = B + 4.18y \quad \text{—— (2)}$$

We have,

$$A = \frac{Q}{V}$$

$$\text{Or, } y(B + 2.09y) = \frac{350}{2}$$

$$\text{Or, } 175 = y(B + 2.09y)$$

$$\text{Or, } \boxed{B = \frac{175}{y} - 2.09y.}$$

We also have,

$$R = 2.79 = \frac{A}{P}$$

$$2.79 = \frac{175}{B + 4.18y}$$

$$\text{Or, } 2.79 = \frac{175}{\left(\frac{175}{y} - 2.09y\right) + 4.18y}.$$

Solving for y:

$$\boxed{y = 3.2\,m}$$

$$B = \frac{175}{y} - 2.09y = \frac{175}{3.2} - 2.09 \times 3.2$$

$$\therefore \boxed{B = 48\,m}.$$

Using free board of 0.75m. Total depth of lined canal

$$= 3.2 + 0.75$$

$$= 3.95\,m.$$